# Fuzzy Kalman Approach to Control the Navigation of Unmanned Aerial Vehicles

Roopashree.S [#1], Shubha Bhat[#3]

[1, 3] Department of Computer Science and Engineering, Dayananda Sagar College of Engineering,
Affiliated to VTU, Bangalore-560078, India.
Deepika K.M [#2]
[2] Department of Information Science and Engineering, Nitte Meenakshi Instiute of Technology,
Affiliated to VTU, Bangalore-560064, India.
[1]roopashree.patil@gmail.com
[2]km.deepika4@gmail.com
[3]shubha22@gmail.com

*Abstract*— **This paper describes the design of Compact, accurate and inexpensive Fuzzy Logic Controllers and Fuzzy Inference Systems which estimates the attitude of Unmanned Aerial Vehicles(UAV).Attitude refers to parameters of Unmanned Aerial Vehicle such as latitude, longitude and altitude and angles of rotation known as pitch and roll. A Soft Computing technique called Fuzzy Logic is used to design the Fuzzy Logic Controllers and Fuzzy Inference Systems. Visual simulation tool and Aerosim (Aeronautical Simulation Set) Flight gear interface are used for Simulation purpose.**

*Keywords*— **Unmanned Aerial Vehicle (UAV), Soft Computing Techniques, Fuzzy Logic (FL), Fuzzy Inference System (FIS).**

## I. INTRODUCTION

An Unmanned Aerial Vehicle (UAV) is an aircraft that flies without human crew. One of the critical Capabilities for making UAV autonomous and practical is the precise estimation of its position and orienatation .The position and orientation of UAV is termed as attitude (Latitude-Longitude,Altitude,Heading,roll and pitch. Usually UAV relies on GPS (Global Positioning System) and INS (Inertial Navigation System) to determine its position and orientation, but if the GPS signal for reasons like adverse weather conditions and hostile jamming becomes unavailable or corrupted, the state estimation solution provided by the INS alone drifts in time and will be unusable after sometime. GPS signal can also be unreliable when operating close to obstacles due to multipath reactions. Therefore when GPS and INS cannot predict and correct the position of UAV, Fuzzy Logic Controllers helps to predict the precise position and orientation of UAV autonomously and in turn helps in navigation of UAV.

The objective of this paper is to demonstrate the design and implementation of an Fuzzy Inference System (FIS) which in turn is fed as input to the Fuzzy Logic Controllers named as Latitude-Longitude FLC, Altitude FLC and Heading FLC to predict the position of UAV and helping in autonomous navigation of UAV .To design Fuzzy Inference System a Soft Computing technique called the Fuzzy Logic is explored. Literature review has revealed the fact that Fuzzy Logic Controllers are designed to control the attitude of UAVs but have failed to give accurate results due to burden of many rules in the controller. Techniques such as Kalman filtering and steady state Genetic algorithms are used to design FIS, but they require a prior mathematical model to estimate the flight parameters, where as Fuzzy logic does not require any reference or pre-existing model to estimate the flight parameters.

In section II the Kalman Filter Based state estimation of UAV is explained. In section III Adaptive Fuzzy Logic Controller is explained. The Design of FIS which is used by FLC is explained in section IV. The results are discussed in section V Conclusion and future enhancements are discussed in Section VI.

## II. KALMAN FILTER BASED STATE ESTIMATION OF UAV

UAVS such as spacecrafts, aircrafts, helicopters, mobile robots are increasingly applied in various domains such as military, scientific research agriculture missile lending etc .Small UAVS have a relatively short wing span and light weight. Small UAVS are called Micro UAVS and are designed to fly at low altitude(less than 1000 meters) and normally they are crashed.

Therefore in navigation of UAV three aspects must be considered. They are
• Plan the correct path for navigation
• Detect the correct position, velocity of vehicle.
• Safely navigate avoiding unexpected obstacles

In general obstacles may not be fully known when the path is designed for UAV. In this case the vehicles have to handle it and navigate when this situation is encountered and in case the original plan designed for UAV is not executable. Therefore our work is focussed on developing a waypoint navigation based autonomous navigation of UAV in which Kalman filter fuzzy approach is made use to generate fuzzy rules when it encounters the obstacles and then feed the rules to controller system of uav so that UAV doesn't execute the previous path and generates a new path automatically based on fuzzy rules and navigate accordingly.
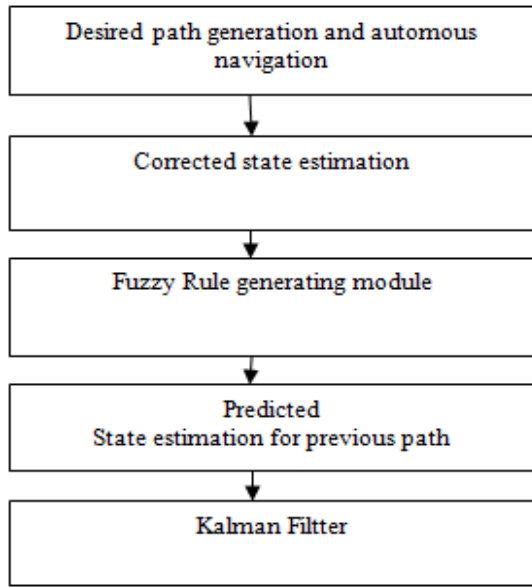
Fig 1: Flow Diagram of Kalman Filter Fuzzy Logic

The essential function of Kalman Filter is to monitor the state of vehicle. State of vehicle in turn means position along X-axis, Y-axis and Z-axis and as well as velocity of vehicle. Usually for all Aerial Vehicles GPS and INS are referred for navigating. But due to some weather conditions several times GPS and INS fail to predict the exact position and velocity of vehicle. To ensure high accuracy and fidelity of monitoring, we use kalman filtering. Kalman Filtering is a form of optimal estimation characterised by recursive evaluation and an internal model of dynamics of system being estimated. Kalman Filter falls into 2 groups. Time update and Measurement update equations. Time update equations are called predictor equations while measurement update equations are called corrector equations.
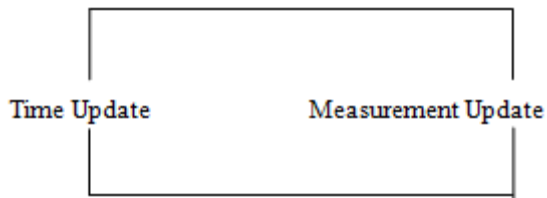


Since sometimes tuning of filter parameters may not lead to generation of exact measurements when obstacles are encountered, Fuzzy rule based filtering approach is proposed so that when obstacles are encountered the exact prediction of position and velocity for UAV is generated.

### III. FUZZY LOGIC CONTROLLER

The purpose of FL Adaptive controller is to detect the bias in the measurements of kalman filter and predict the exact position of UAV. In FLAC GPS and INS measurements are combined and hence the disadvantages of GPS and INS are ideally cancelled and then Fuzzy rules are applied to the combined measurements of GPS and INS for more accuiracy.The structure is as shown.
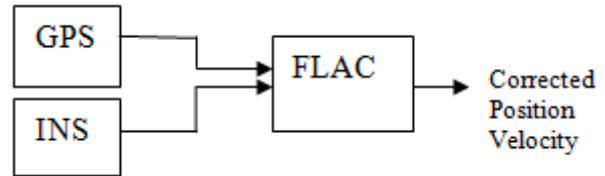


Fig 2: Structure of Adaptive Fuzzy Logic Controller

### III. SIMULATION ENVIRONMENT

The membership functions for fuzzy control are shown below figure



Fig 3: Fuzzy Membership Function for Altitude

For membership functions Fuzy Logic toolkit is made use in simulink/matlab environment. The fuzzy rules are generated using Fuzzy lnference editor in MATLAB and are shown below.The derived Aerial Controller model is shown in Fig.3. It consists of following Subsystems.

1) Fuzzy Logic Controller: It is composed of combination of Altitude, Latitude-Longitude and Heading Fuzzy Logic Controllers.

2) Scaling Embedded Matlab Function: it contains aircraft states as the input and calculates the scaling factor.

3) Altitude Embedded Matlab Function: it takes scaling as the input and calculates the change in altitude.

4) ErrorCalc Embedded Matlab Function: It Contains two inputs called Altitude and Airspeed. This block contains conditions to Control the Elevator and throttle of Aircraft.

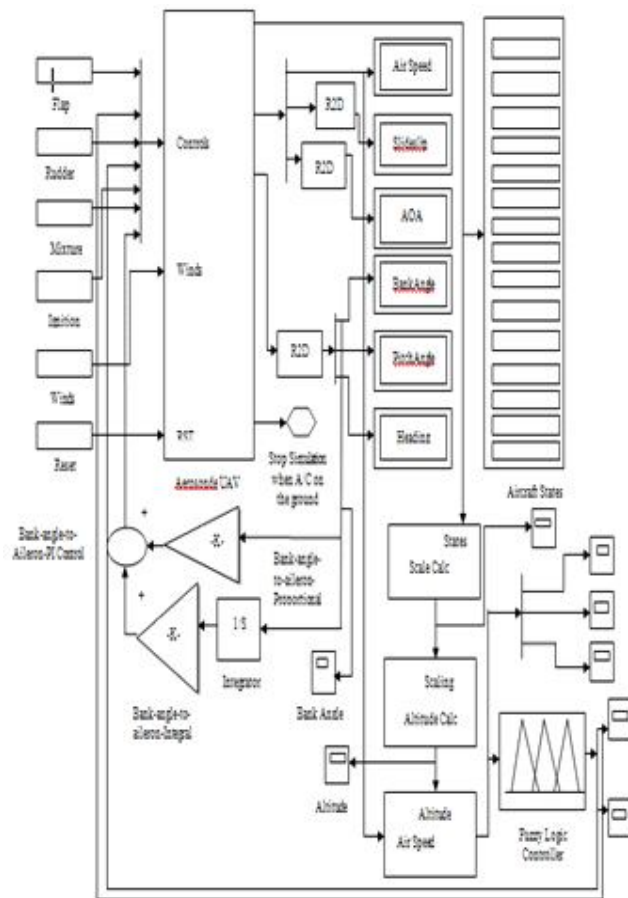The Functional model Altitude fuzzy logic controller is shown below:

Fig. 4 Demonstrating the Aerosonde Simulation Model for Estimation of altitude of Unmanned Aerial Vehicles

## IV. RESULTS

Considering the model shown above the Fuzzy Inference system for all the three modules of Fuzzy Logic Controllers is designed. The Fuzzy Inference System (FIS) for Altitude Fuzzy Logic Controller is designed and displayed in the Graphical User Interface (GUI) of Fuzzy Logic Toolkit using Matlab.The below section also explains about the command outputs of FLC which are obtained when simulation model is run for a specified time. The inputs to the Altitude controller are:

> Altitude: The altitude at which the aircraft will be trimmed.

> Airspeed: The airspeed at which the aircraft will be trimmed.

> Altitude Error: It is the difference between the desired altitude and the current altitude of the airplane.

> Change of Altitude: The error indicates whether the, aerial vehicle is approaching the desired altitude or if it is going away from it.

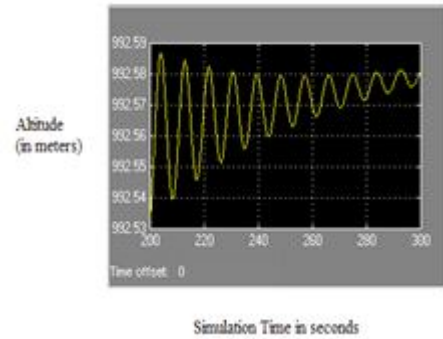The graphs of inputs are shown below:
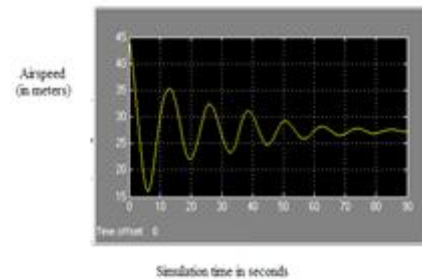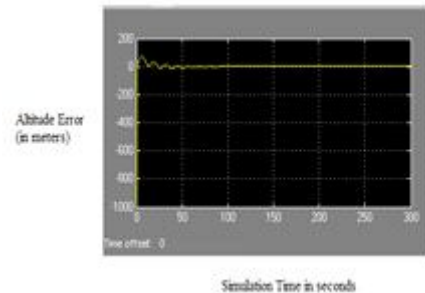


Fig.5 Altitude of UAV
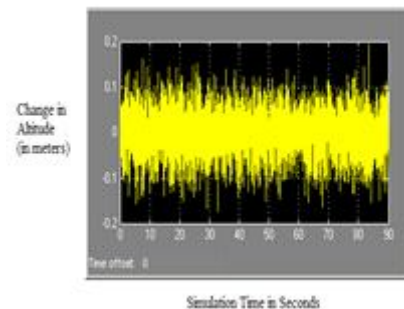


Fig.6 Airspeed of UAV



Fig.7 Altitude error



Fig .8 Change of Altitude Error

The command outputs to the Altitude controller are:

> Elevator: The initial guess for the elevator position at trim condition.

> Throttle: The initial guess for the throttle position at trim condition.

> Scaling: This is the factor that indicates uniform change in altitude from one waypoint to another. Constant scaling in maintained when flight is navigating from one waypoint to another.
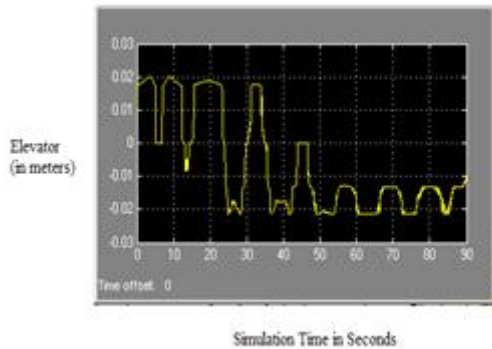
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The graphs of command outputs are shown below:



Simulation Time in Seconds

Fig 9: Elevator of UAV



Simulation Time in Seconds

Fig .10 Throttle of UAV



Simulation time in Seconds
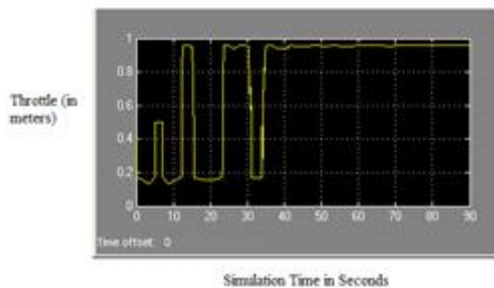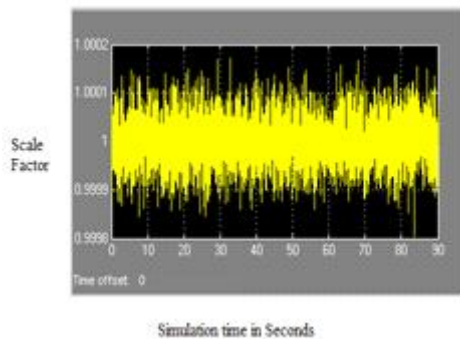
Fig.11 Scaling of UAV

## V. CONCLUSION AND FUTURE ENHANCEMENTS

The purpose of this paper is to demonstrate the Fuzzy Logic Controller which is used for Waypoint Navigation and Control of Small Aerial Vehicles. Fuzzy Logic is the best and promising technique to control Aerial Vehicles when precise mathematical models are not available. Fuzzy logic controllers have the following advantages over the conventional Controllers. Experiments show comparable results with conventional systems like Kalman filter and particle filter.

They are cheaper to develop, they cover a wider range of operating conditions, and they are more readily customizable in natural language terms. A self-organizing fuzzy controller can automatically refine an initial approximate set of fuzzy rules. Simulation Studies have shown adequate overall performance but sometimes controllers may be overloaded with many inputs and outputs which in turn increase the rules that are generated to control the attitude of UAVs and thus degrade the tuning of parameters of UAVs. To overcome the rule expansion a method called Combs method is employed to select minimum number of inputs and outputs. This in turn reduces the membership functions and thus the Controllers are not overloaded. The attitude of UAV may oscillate because the controller design is based on human pilot experience. In order to achieve better results the Controller can be designed on flight performance observations.

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